# Network Modeling and Simulation

ITO/DARPA

April 2-4 PI Meeting

John Martin (BFM)

Jennifer Mekis (BFM)

Sri Kumar (PM)

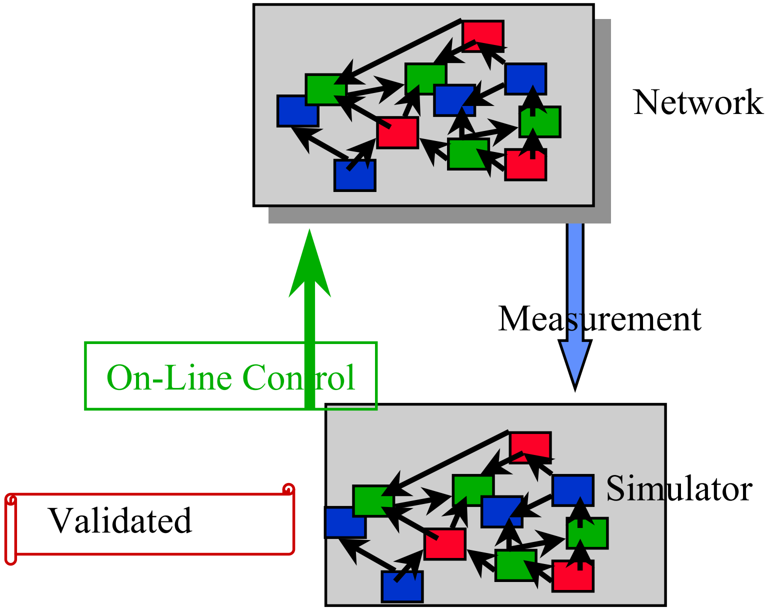
San Diego

Supercomputer Center

# Network Modeling and Simulation

**Goal:**

**Create Network Modeling and Simulation Tools that are trustworthy to provide a basis for on-line prediction and network control**



# New Capabilities

- **Prediction**
  - End-End, Internal Behavior
  - Anomaly, Faults
  - Multi-scale (time, size), Multi-Resolution
- **Control**
  - Parameter tuning
  - Dynamic deployment of protocols
  - Rapid provisioning: BW, QoS

**Human in the Loop. Reduce/eliminate**

# Four Fold Path for Next Year

## Build on this year's work

- **Wholesome: Better linkage in PI work/ Integrated efforts**
- **Think: Measurement ←→ Modelers**
  - Have we done enough?
  - What next?
- **Defense: Engage to DoD problems; establish links to clients**
- **Experiment: Define, execute integrated experiments/demos**
  - QoS, Failure Prediction
  - Multi-scale characterization/visualization of network performance
  - Engage DOD agencies in joint experimentation
  - Engage Multi-ISPs in experiments?

**Tuesday PM Breakout Sessions**

# Agenda Monday

- **0830 – 0900 DARPA**
- **0900 – 1200 Review: New Models**

  **(20 minutes each + Break)**
  - **UC Berkeley/CISCO**
  - **UIUC**
  - **Caltech/ISI/Maya**
  - **Rice**
  - **Renesys/ATT/Princeton**
  - **U Mass**
  - **U MD**
- **1200 -1330 Lunch**
- **1330 – 1520 Review: Measurement/Simulation/Emulation**

  (20 minutes each)
  - **Renesys**
  - **Georgia Tech**
  - **Maya**
  - **CAIDA**
  - **CNRI/ATT/Intel/SLAC**
  - **UC Riverside**
- **1600 – 1800 Infomercials and Demo/Poster Session**

# Agenda Tuesday AM

- **0745 – 0830 Charlie Plott, Caltech**
- **0830 – 0915 Review: New Models**
  - UC Irvine
  - Purdue
  - U Missouri/Rutgers/Georgia Tech
- **0915 – 1015 Review: Simulation**
  - SAMAN/ISI
  - RPI
  - SAIC
- **1015 – 1030 Break**
- **1030 – 1200 DOD Panel. Organizer – Al Legaspie, SPAWAR (Presentations and Q&A)**
  - Navy- **Captain Joseph Celano** Head, SPAWAR Modeling and Simulation
  - Air Force: **Major Rusty Baldwin**: Air Force Institute of Technology
  - Army – **Major Dave Williams**
- **Luncheon Speaker:: CDR James Soriano,Tactical Flag Command Center, CENTCOM**

# Breakout Sessions: Tuesday PM

- **Session 1: QoS and Overlay Networks**
  - Session leaders: Shiv Kalyanaraman (RPI) and Jean Walrand (UCB)
  - Discussion leaders: Srikant (UIUC), Ogilenski ( Renesys)
- **Session 2: Measurement: What it is and what it ought to be**
  - Session Leader: K Claffy (CAIDA)
  - Discussion Leaders: Hajek (UIUC), Willinger (ATT), Towsley (UMass), Reidi (Rice), Jaffe (Cisco), others: TBD
  - Model Validation
  - On-line network control
- **Session 3: Integrated Experimentation/Demonstration (Late FY01, FY02)**
  - Session Leader: Fujimoto (Georgia Tech)
  - Discussion Leaders: Bagrodia,
  - Multi-operator network test beds
  - DOD Network test beds
- **Session 4: Architecture and Integration**
  - Session Leaders: Gary Warren (SAIC), Heideman (ISI)
  - Discussion Leaders: Baras (UMD), Others: TBD
  - HLA, APIs, Interoperability to support Exp/demos
- **Session 5: Program Links to DOD applications**
  - Session Leader: Al Legaspie
  - Discussion Leaders: TBD
- **Session 6: Open (TBD on site)**
  - Possibilities: Early discussion of game theory
  - More on Measurements

# Agenda Wednesday

- **0800 – 1100 Report from breakout sessions**

  **Each session 20 minutes (0800 – 1000)**
- **Plenary and Planning – one hour (1000 – 1100)**
- **Wrap up/Vote of thanks ( 1100 – 1105)**
- **1105 Adjourn**
- **------------------------------------------------------------------**
- **Game Theory based IT 1 – 3: 30 in Hotel**

# News

- **Entering Performers**
  – K. C. Claffy (CAIDA)
  – C. Plott (Caltech)
  – Mortazavian (UCLA)
  – J. Hou (Ohio State)

- **Exit**
  – None

# Admin Notes - 1

- **Thanks to UCSD, Supercomputer Center**
  - Facility
  - Refreshments for demo/poster session
  - KC Klaffy, Theresa, Rebecca
- **If you want to do an infomercial for poster/Demo, and if you haven't already signed up, Pl see John or Jennifer before lunch.**
- **Pl sign up which breakout sessions you would like to participate in**

# Admin Notes - 2

- **Your Slides – Send to John Martin by email COB Friday 6 April.**
- **$$ - If you haven't paid the registration, pl do so.**
- **Buses**
- **TRIP to SPAWAR**
  - Limited to 20

# Experimentation/Demonstration

- **Develop Models and Predict Traces of networks – 100s of nodes**
  - End-End delays, Congestion, Instability
  - Evaluate Fluid and end-end models
- **Demonstrate control in Lab networks**
  - E.g., parameter tuning
- **Demonstrate multi-scale characterization/visualization of network performance**
  - 1K+ nodes
- **Engage multiple ISPs for multi-operator experimentation**
- **Engage DOD agencies in joint experimentation**

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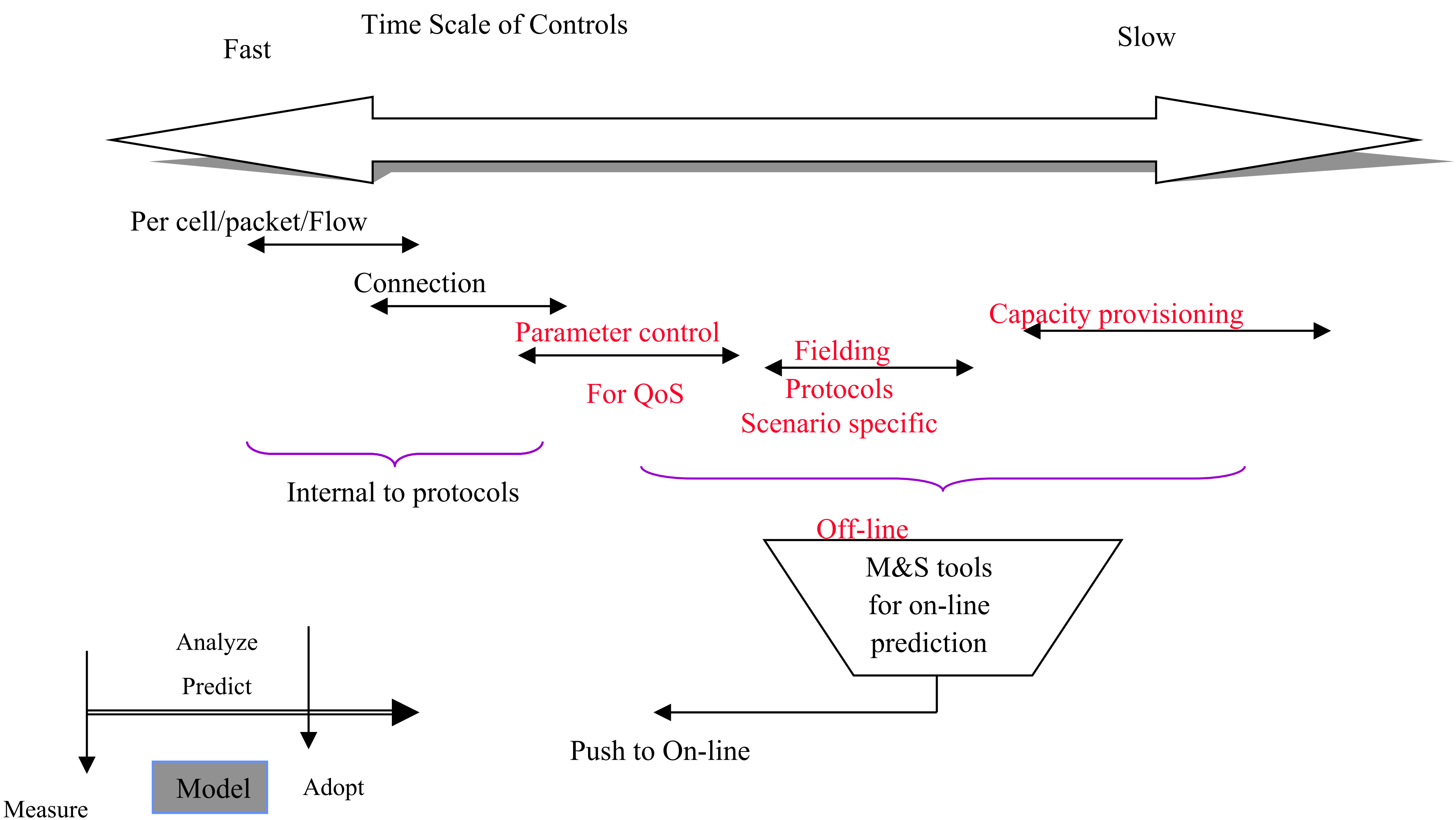
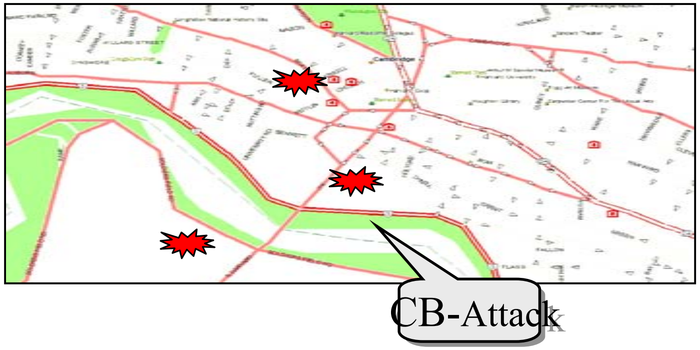
# BACK UP

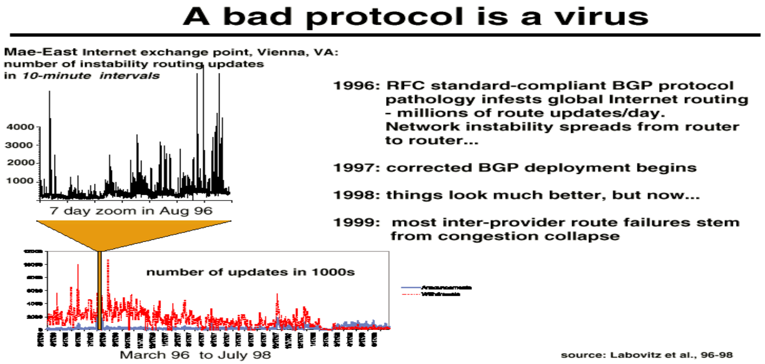
# On-line Network Control



# Impact and Significance

- **Lack of understanding has led to ad hoc methods and operator in the loop**
- **Improved Modeling and on-line ability will result in orders of magnitude improvement in time and cost for DoD**
  - Parameter tuning to improve performance
  - planning, provisioning of capacity, topology to meet requirements
  - Failure detection and response
- **Fast dynamic provisioning**
  - One hour of a massive bio-attack.
- **Hardening of COTS**
  - Analyze protocols/ new technologies
  - Routing instabilities




# Program Tasks

- **New Models of Traffic, Network, and Control**
  - Fluid Models: Physics of network traffic
  - Empirically derived end-end models
  - Scale, Model reduction, Control Models

**U Illinois**
**UC Berkeley**
**U Maryland**
**U Mass**
**Caltech/Princeton**
**Purdue/Kansas**
**Riverside, LANL**

- **Measurement, Model Validation**
  - Experimental Infrastructure
  - Active, Passive sampling

**CNRI (15 Companies)**
**CAIDA, NIST**
**SAIC**

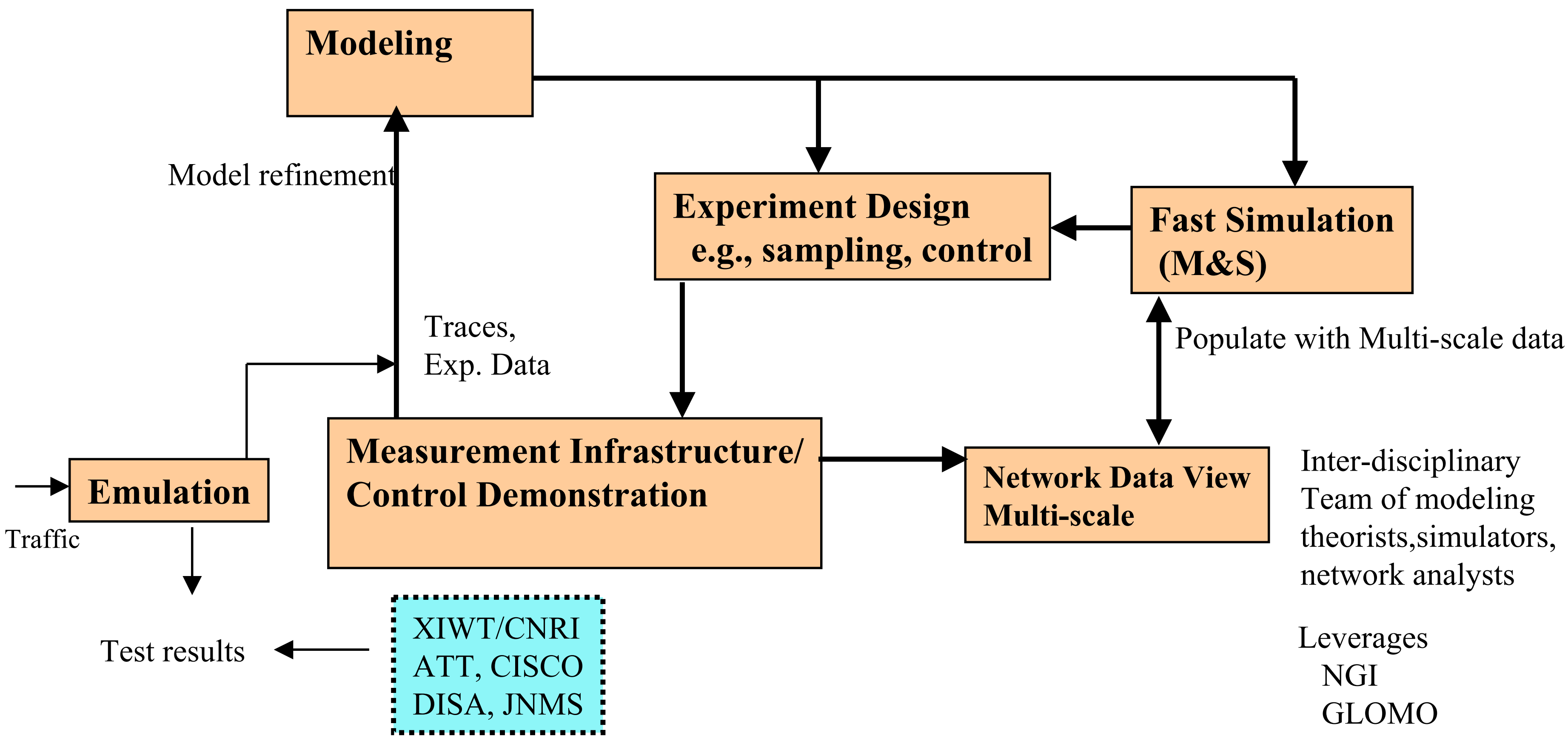
- **On-line simulation**
  - Integrate models and event simulation
  - Populated with on-line data
  - Quick, Scalable, Parallel/Distributed

**RPI**
**Renesys/ATT**
**UCLA**

- **Emulation**
  - Programmable interpreter

**Georgia Tech**

# Program Components




**Industry: CISCO, ATT, Iperf/XIWT (HP, Intel, Ameritech, SWBell, IBM, other members), CAIDA**

**Government: NIST, DOE (SLAC, ONL, LANL)**

**DOD Clients: DISA, JNMS, SPAWAR, RL**

**Future: Other ISPs for multi-operator experiments**

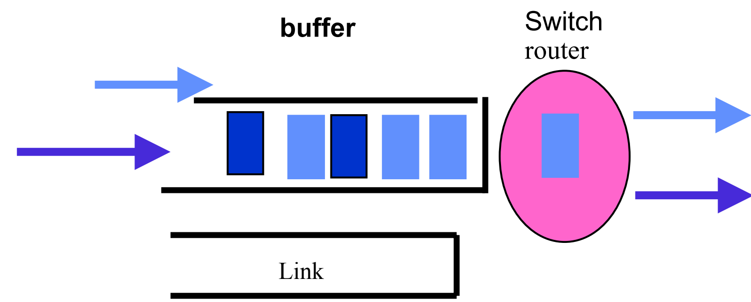
# Fluid Models of Packet Flow

**Leverage Law of Large Numbers**
- **100s packets is a drop**
- **Diffusion approximation**

**Differential Equation driven by stochastic inputs**

**Capture Long Range Dependence**

**Fluid Models of Service/Network**
- **Generalized Processor Sharing**




From Packets to Flow/Fluids

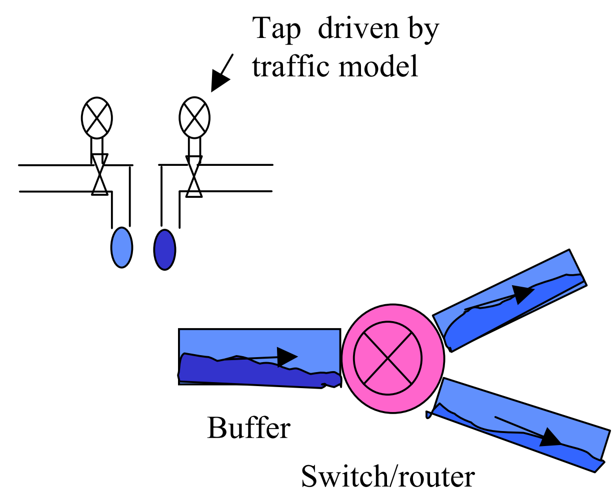
**Theory:**
**UMASS, Berkeley, UIUC, Caltech**

**Implementation:**
**UCLA, LANL/NIST**

**Simulate/Analyze:**

**Delay, Loss Rates**
**Congestion, Instabilities**

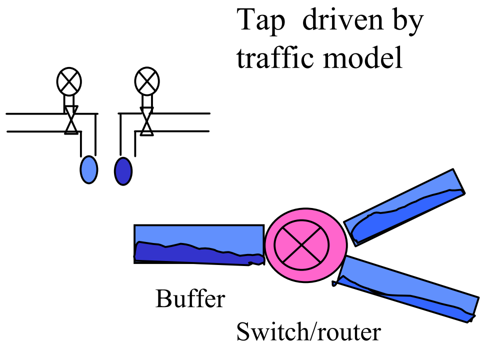
**Turbulence?**




Fluid level -> no. of packets
Overflow -> loss rate

# Fluid Network/Service Model

| Actual | Model |
| --- | --- |
| Buffer size N packets (discrete) | Container of N fluid units (continuous) |
| Link average speed B packet/sec | Emptying rate B units/sec |
| Buffer overflow rate | Container overflow rate |
| Different traffic types | Non-colloidal fluid |
| Congestion (> x packets) | Container level (> x) |
| Propagation delay z | Pipe of length z; normalized diameter |
| Average delay at link | Reciprocal of flow rate |
| Thruput | Flow rate |
| Switch/Router Disaggregation | Generalized Processor Sharing |
| Priority | |
| Routing | |




Model Capability:

Picking up events every 100 packets or so

Good enough for congestion, average delay

Lost: packet level details

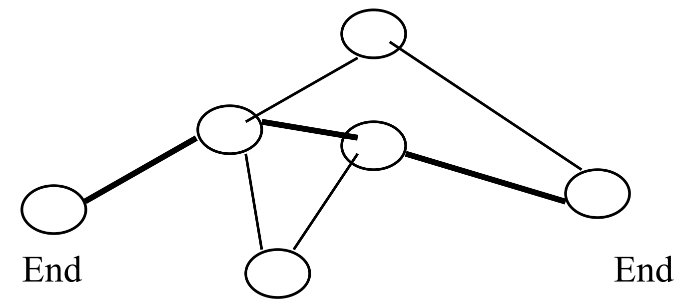
**Generalized Processor Sharing: (Gallagher/Parekh)**

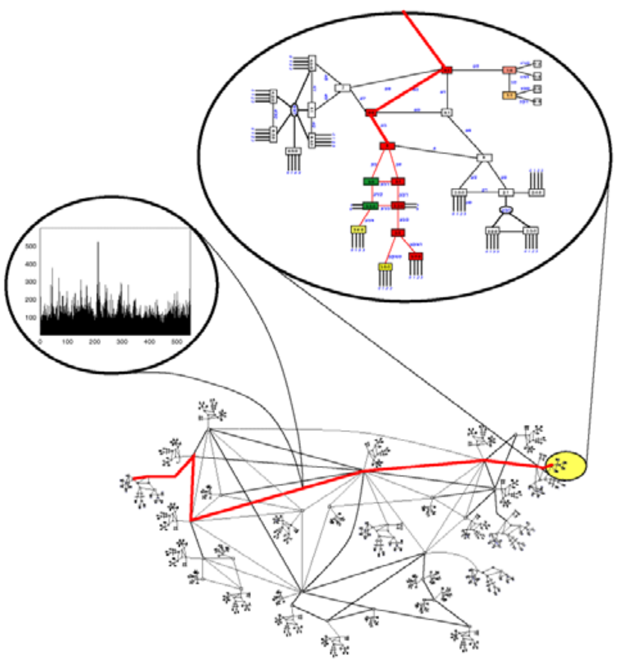
**Instantaneous Emptying/Routing rate = Function (Priority, policy, routing, buffer contents...)**

# Empirical Models: Multi-Scale

- **Direct On-Line fitting of models to path, end-end data.**
  - Delay, Error Rates
  - Adaptive model fitting
  - Measured from Edges
  - Inferring link data from edge measurements (tomography)
- **Multi-Scale**
  - Exploit multi-fractal, self-similarity in data
  - Variety of observed network data exhibits fractal nature
    - » Delays, web traffic, inter-arrival times of packets
    - » Aggregate Traffic
    - » Network size (edges, links)
  - Density falls as power law
  - HOT: Highly optimized Tolerance Theory

**Renesys, UMD, Rice/Princeton**
**Caltech/UCLA, Kansas**
**And Measurement Team**

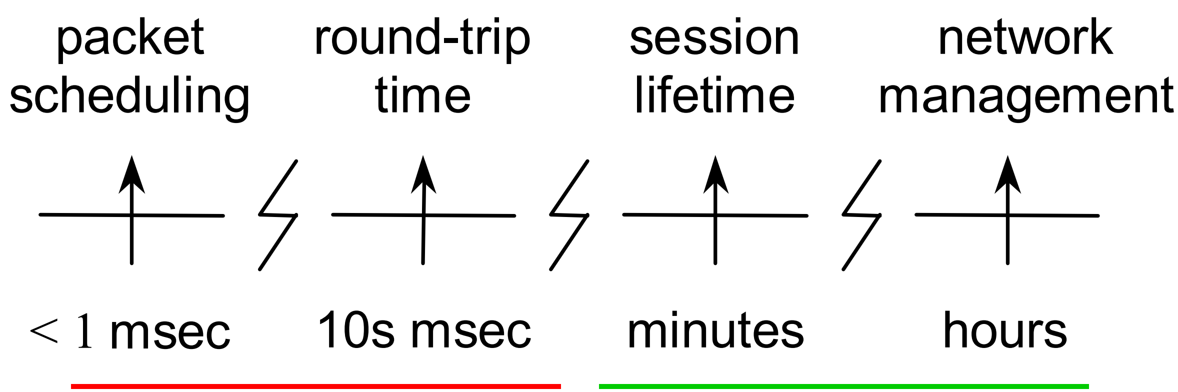


# Multiscale Nature of Traffic

- Multifractal **(Riedi et al '97)**
  - –small time scales
  - –network, protocol layer
  - –control at connection level

- **LRD (Willinger'93, Varaiya '96 and others)**
  - – large time scales
  - – client behavior
  - – bandwidth over buffer




Self Similar subclass of MF a subclass of LRD

# Fractal Trace Analysis

- **Study a random process in terms of how its moments scale as we zoom in/out (*multiscale*)**

- **Classical approach:** **2nd order moment (variance) scaling**

- **Ideal, *fractal* scaling with Hurst parameter $H$**

$$x(at) \quad \text{"looks like"} \quad a^H x(t)$$

**zoomed**

**in the sense that**

$$\mathrm{var}[x(at)] = \mathrm{var}[a^H x(t)]$$

- **Example: fractional Brownian motion (fBm)**

  Special case: Self similarity

# Multifractal Trace Analysis

- **Fractal analysis limited to *2nd order* statistics**

  **> natural for Gaussian processes only**

- ***Multifractal analysis*: study scaling of *higher* and *lower* order moments:**

$$x(at) \quad \text{“looks like”} \quad a^{H(k)}\, x(t)$$

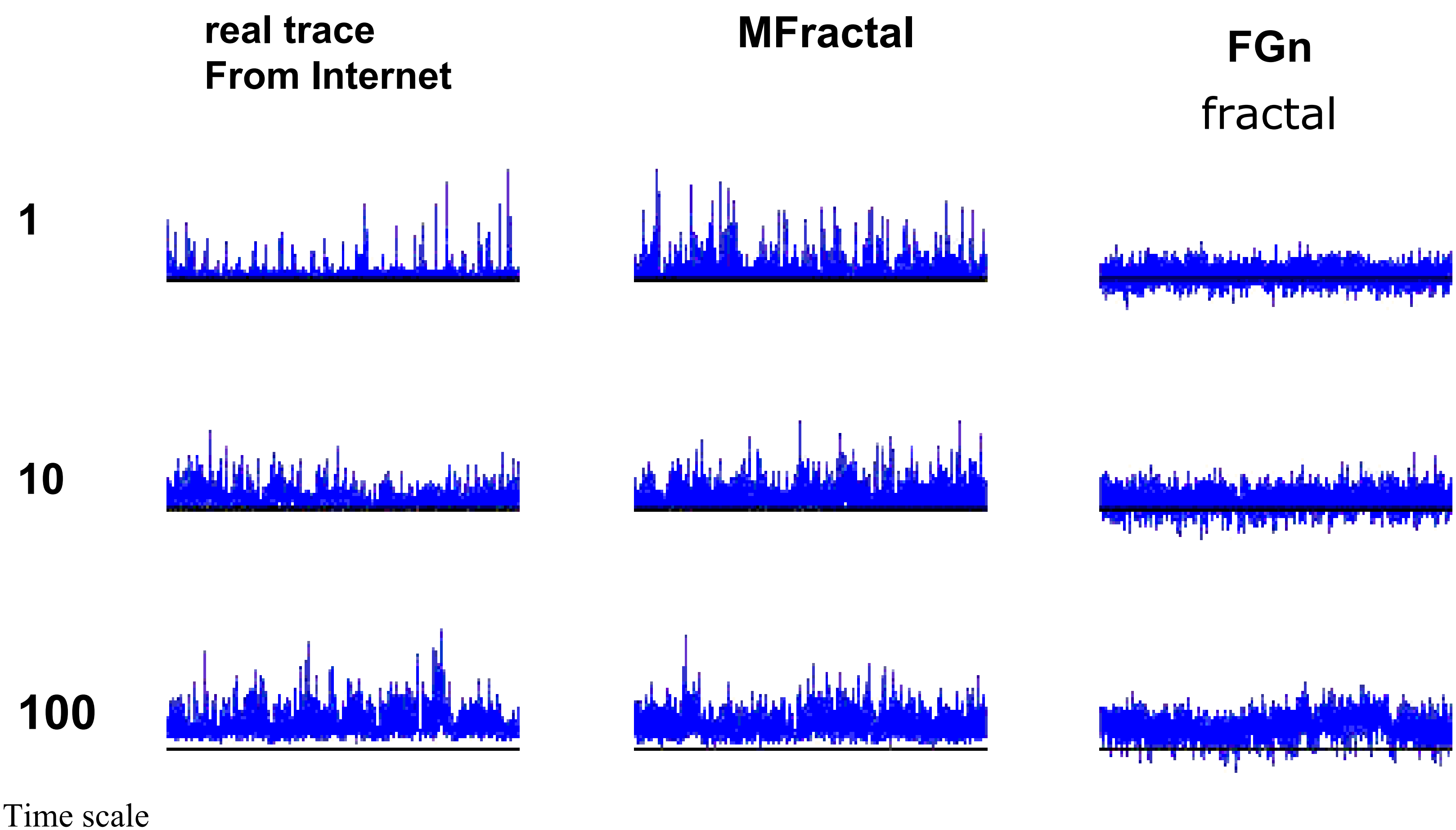
**in the sense of $k$-th moments**

$$\mathrm{mom}_k[x(at)] = \mathrm{mom}_k[a^{H(k)}\, x(t)]$$

- **Natural for many nonGaussian processes, particularly bursty network traffic**

# Multifractal Modeling

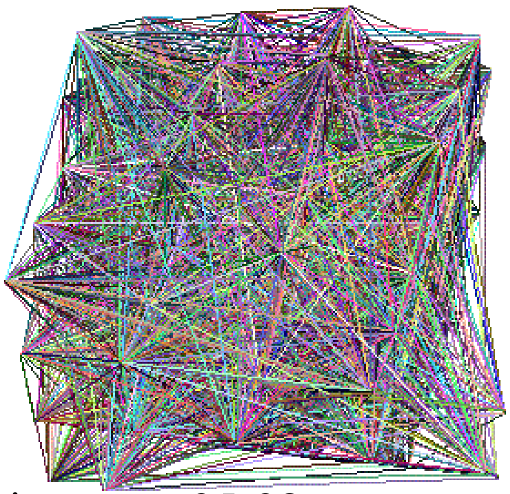
- Multifractal model: Estimation, fitting theory known.




Data: Round Trip delay between two specific nodes.

# Scaling: Empirical Observations

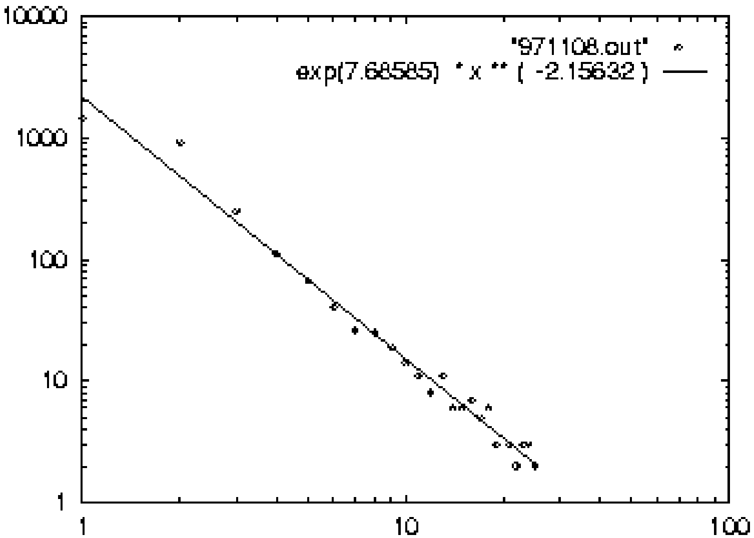
UC Riverside
CAIDA



Internet instance, 95-98

From CAIDA

Degree of node = Number of Edges




Power-law: Frequency of degree vs. degree for Autonomous systems

- Empirical Observation: Frequency of degree (d) = d**(-a)
- Remained so even with network growth.
- Questions:
    - What is the implication on performance as network scales?
    - What is the performance scaling relationship between an 1K node network and a 100K node network given both have the same power law?

# Control Models

UC Irvine, UI Urbana, Berkeley

- **Parameter Tuning (TCP, Web)**
- **DIFFSERV**
  - Measurement Based
  - –COS Provisioning
- **MPLS**
  - –Adaptive resource allocation
- **Pricing Models**

FM with new window adjustment for differentiated services in TCP

$$\frac{d}{dt}w_i(t) = -\kappa \frac{d_i}{\bar{d}_i}\frac{s_i}{w_i},$$

$$\bar{d}_i = d_i + A_{i}.q$$

$$s_i = w_i - x_i d_i - p_i \text{ for } i = 1, \cdots, N.$$

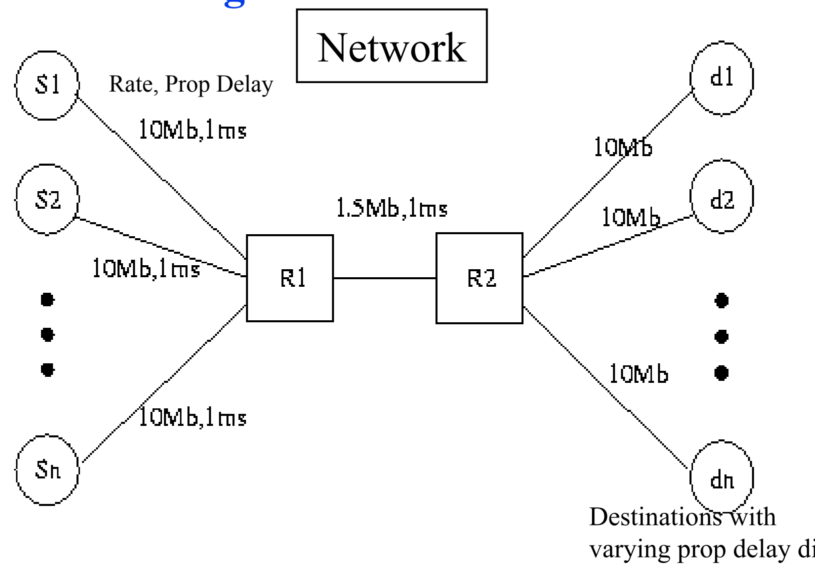
W - window size

A - Incidence matrix

d - prop delays

x - data rate

## Example: QoS Provisioning. Distributed TCP Control




FM vs. NS

| target($p_i$) | throughput | throughput ratio | target ratio |
|---|---|---|---|
| 2 | 420 | 1 | 1 FTP |
| 6 | 1117 | 2.66 | 3 |
| 10 | 1863 | 4.43 | 5 |
| 14 | 2628 | 6.26 | 7 |
| 18 | 3353 | 7.98 | 9 Video |

# Measurement/Experiment Infrastructure

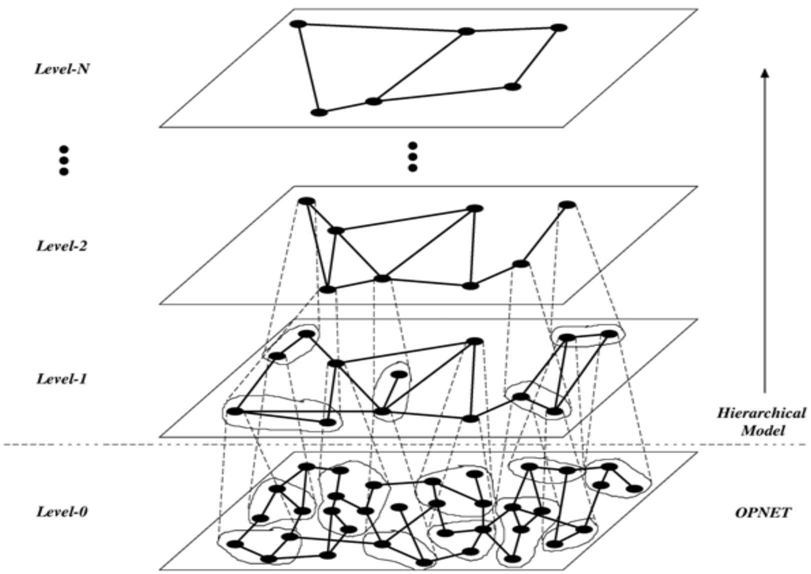
- **IPEX:**

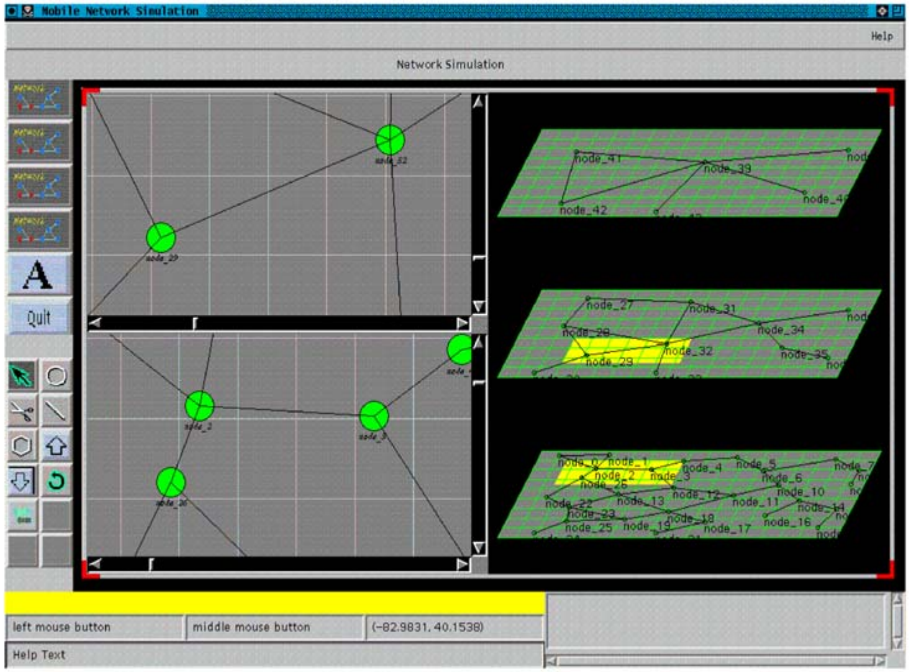
  **"Internet Performance Exchange" XIWT/CNRI**

  - **Industry Lead, Readily Configurable, Accessible Internet Testbed for Performance Measurement, Experimentation and Data Generation**
  - **Mesh Measurement.**
  - **Generate baseline data series for testing concepts of normal and anomalous performance**
  - **"Plug and play" environment for researchers' use: ready access, available analysis & measurement tool library, data collection/security services**

- **CAIDA**
- **ATT/CISCO**
- **DISA (Netwars)**
- **JNMS**
- **SPAWAR, JTRS**

# Adaptive Hierarchical Modeling Incorporating On-Line Measurements



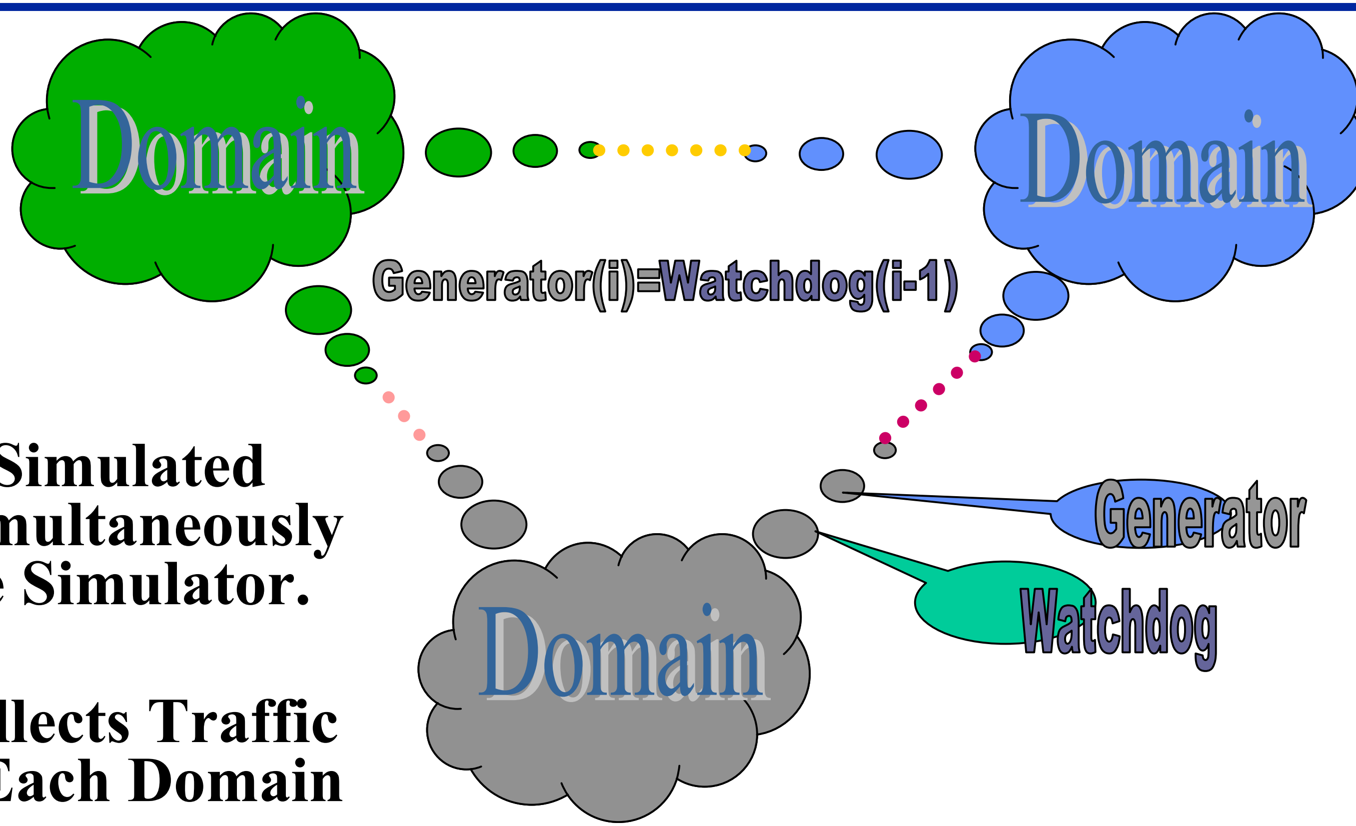

**Topology**
**Traffic pattern**
**Routing policy**
**Call admission control (CAC)**

→ **Performance Models** → **AD processor** → **Model and its sensitivities** → **Multi-objective designer/optimizer** → **Design parameter**

**QoS estimates:**
**End-to-end delay**
**Call blocking**
**Throughput**

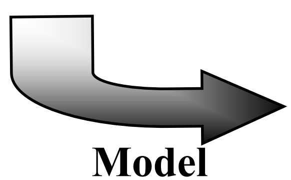
# Distributed On-line Simulation

Network Decomposed Into Domains.




Each Domain Simulated Separately, Simultaneously Using On-Line Simulator.

Watchdog Collects Traffic Outflow For Each Domain Over time intervals.




Model Generator Produces Traffic Inflow From Other Domains .

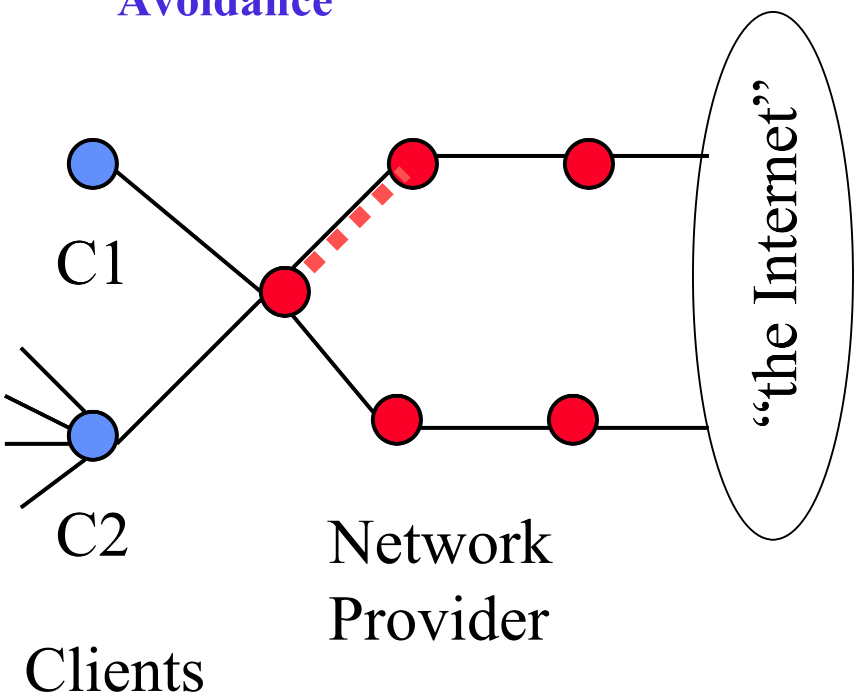
Convergence

Time Step

RPI, Renesys/ATT, UCLA

# Fault Analysis

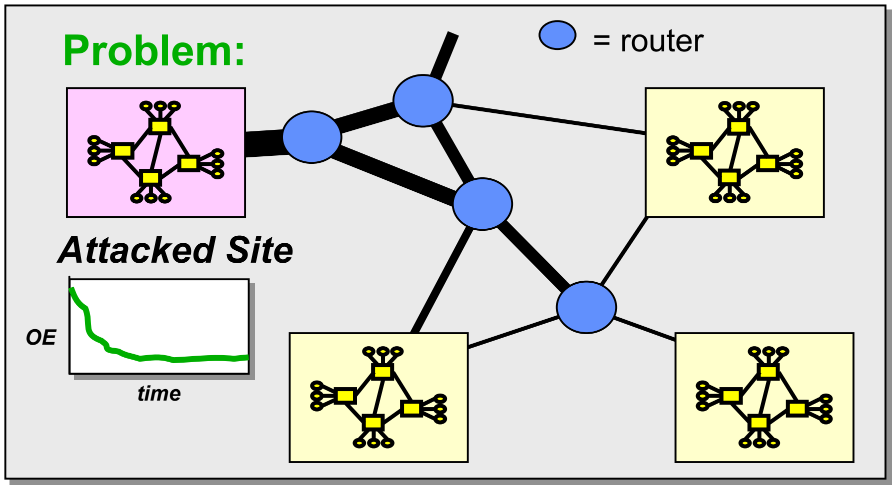
**USC/ISI**
**Prediction, Detection, Avoidance**

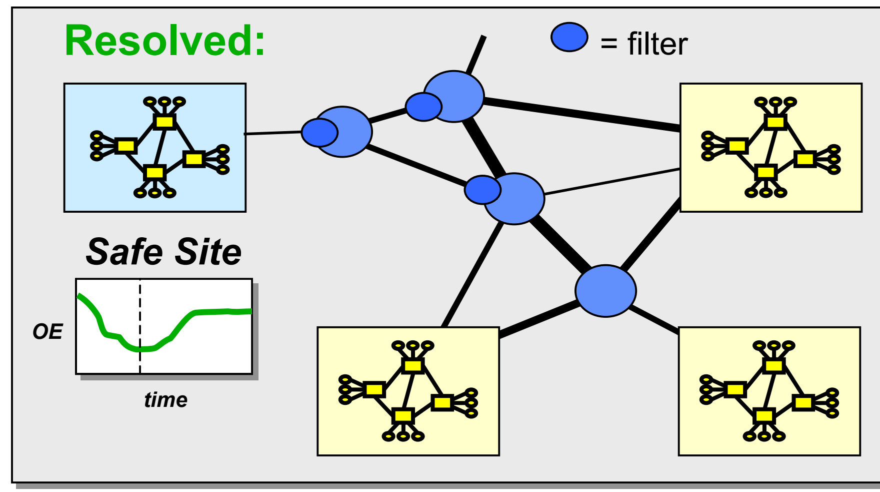



- **What if the red link becomes overloaded?**
  - Today: discover the symptom (high loss)
- **USC/SAMAN will help identify the cause:**
  - Change in C2 traffic mix?
  - Interactions between C1 and C2 traffic?
- ***Use of M&S to:***
  - Predicting and avoiding failures
  - Cascading failures
  - Planning failure recovery strategies
- **SAMAN – Simulation augmented by measurement and analysis.**

# *Information Assurance*

- **Improved OE (operational effectiveness) of communication networks.**
  - Improved ability to detect network problems.
  - Improved ability to respond to detected network problems.




**Collaborate with FTN and DCN Programs ITO**

# Emulation

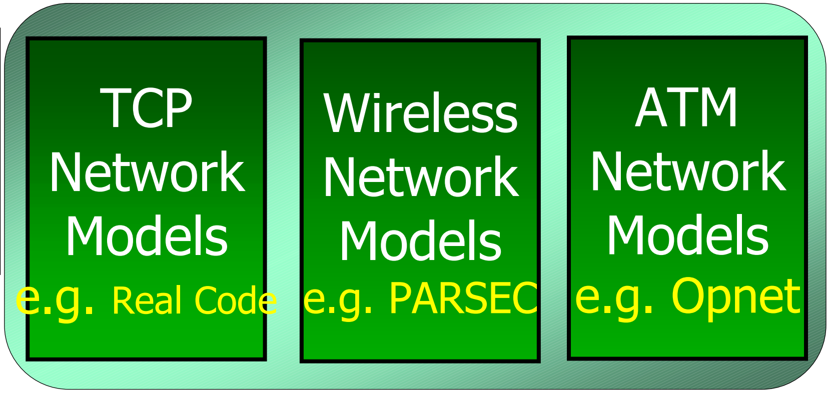
Georgia Tech

**Larger scale, more detailed models of emulated network**

Solution: Parallel & distributed real-time execution of discrete event models

**Need plug-n-play methodology for heterogeneous emulation tools**

Solution: Emulation *backplane* approach




**Need repeatable execution capability**

—for improved debugging and testing support

Solution: *Direct execution* of end-user applications, and discrete event simulation of network-node models